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EXTENDING FIN CONCEPT FOR A 105-mm FIN STABILIZED PROJECTILE

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INTRODUCTION

The U.S. Army is seeing more demand for precision guided munitions. The complexity of combat in urban settings requires novel fighting techniques and strategies; driving requirements for new armament technologies. Design and development of precision guided projectiles is already in place for field artillery and mortars. Though a precision 155-mm projectile (Excalibur) has already been developed and fielded, there is still ongoing work being done to provide a 105-mm precision guided solution.

A recent desire is to provide a base kit solution that is able to fully integrate into a standard 105-mm round. Thus, the extending fin concept was being designed for these 105-mm projectiles. The base kit is comprised of six extending fins which after muzzle exit of the gun, will deploy outwardly into the airstream. Once the fins are in the deployed state, they serve as a stabilizing device for the projectile. The difficulty in the design is characterized by the constraints it has upon it. The base intrusion into the cartridge case dictates a maximum stowed length of the fins, while the requirements for gyroscopic stability demand longer fins for those M1 and M913 projectiles.

DETAILED DESIGN

The extending fin base design is unique because the fins not only rotate out and away from the projectile body; they also slide out through an "s" shaped cam channel (detailed later) extending the fins further into the airstream. Having the fins further away from the body allows the fins to engage the more laminar airflow as well as possess a greater moment arm in controlling the stability of the projectile. This is critical in certain applications as it will provide the necessary center of pressure for the projectile's aeroballistic requirements.

Figures 1 and 2 display a cross-section and isometric view of the base with the extending fins in their stowed configuration. For easy assembly, the obturator (2) slides onto the base (1). Then the spacer (3) and fin mount (4) are assembled behind the obturator (2) and fastened to the base with the retention nut (5). The said projectile contains a multi-piece base that allows for a one-piece solid obturator (2) to be incorporated into the overall base design without any complex assembly procedures such as a shrink fit or press fit as is with previous art. The fins (7) and fin hubs (6) are aligned with respect to the fin's "s" shaped channel and assembled by fastening the screws (8) through the fins (7) into the hubs (6). The extending fin sub-assemblies are positioned in slots in the base fin-mount (4) and the shafts (9) are inserted into holes attaching the fins (7). The retention plug (10) is inserted into the base and all six extending fin sub-assemblies are located and stowed in the slots of the plug (10). The retention disk (12) fits over the fins (7) flush with the retention plug (10). The retention bolt (11) is then inserted into the plug (10) and disk (12) to fasten them to the base (1). In this fin configuration, the multi-piece base is incorporated into a full projectile and fired in the 105-mm cannon.

When the projectile is launched, orifices in the retention plug (10) allow burning gases into a chamber between the retention plug and the base. As the projectile leaves the gun tube, a pressure differential builds such that the pressure exterior to the base is closer to atmospheric, while the pressure in the chamber is significantly higher. This pressure differential pushes on the retention plug (10) and fails the bolt (11) in tension. The retention plug (10), disk (12), and bolt (11) are pushed out rearward and the extending fins (7) are released to begin their deployment. Further technical information on the fin retention and deployment system is found in the pending technical papers by Robert Terhune, Christian Kessler, and Adrian Blot. During

deployment, the fin hubs (6) will rotate forward until they contact the spacer (3). At this point, the fins (7) cock forward releasing themselves to freely slide through their cam channel. A combination of aerodynamic drag, centripetal force, and a spring lever [13 (fig. 3)] contribute in extending the fins (7) outward into their deployed locking state while also forcing the fin hubs (6) rearward until they lock at their deployed state. The fin shafts (9) contain locking detent springs that locate the entire extending fin assembly at the desired angle. Figure 4 displays the concept with the extending fins and multi-piece base in their tactical deployed state.

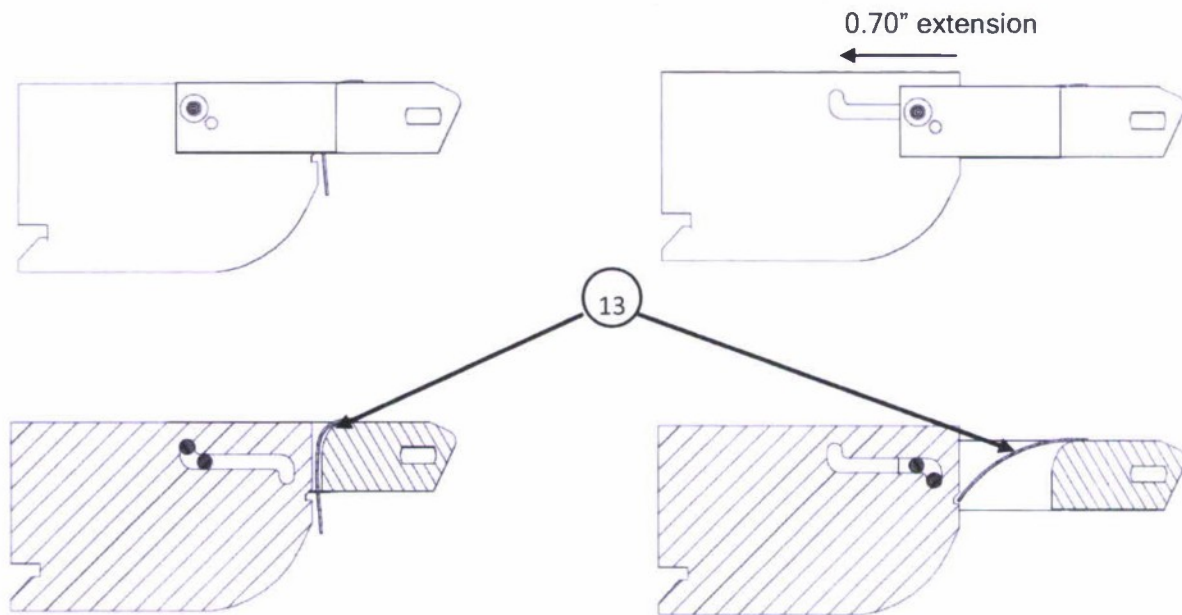


Figure 3
Side view and cross-section view of the extending fin sub-assembly in both the stowed and deployed configuration detailing the spring locking lever

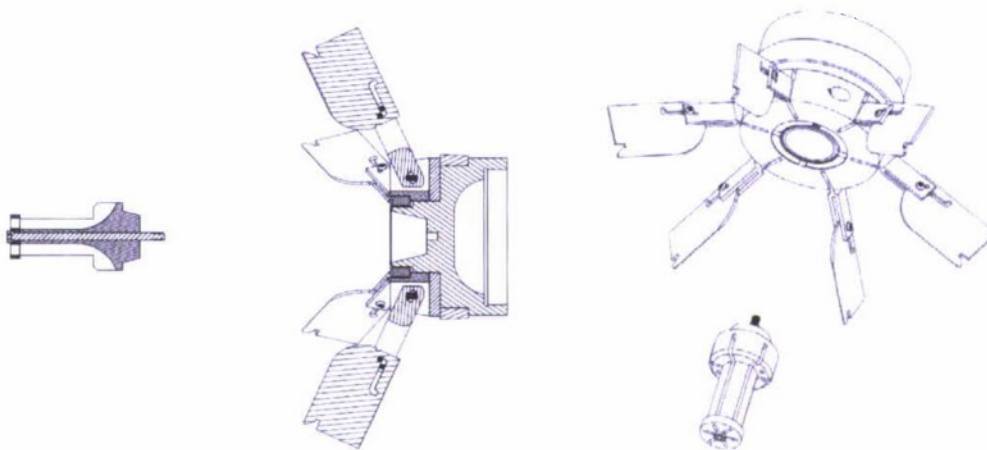


Figure 4
Cross-section view and isometric view of the projectile multi-piece base with extending fins in the deployed configuration

The extending fin sub-assembly design is a novel design given that the fin hub (6) is able to support the fin's own inertial setback loading during gun launch while still having the ability to slide out further into the airstream after muzzle exit. The "s" shaped cam channel in the fin (6) provides the necessary platform for this solution. During gun launch in the stowed configuration, the fins (7) are unable to rotate out because of the retention disk (12). Because the fins (7) fail to rotate with respect to the fin hubs (6), the screws (8) act as a translational stop in the channel and allow the hubs (6) to pull the fins (7) through gun launch relieving any inertial loading they would exert on the retention disk (12), pug (10), and bolt (11). Figure 5 displays the extending fin sub-assembly in this stowed configuration. Once the retention disk (12) is removed after muzzle exit, the fins (7) have the ability to rotate away from the hubs (6) and the fins (8) slide outward from the hubs (6). The spring levers (13) assist the fins (7) in sliding through the cam channel and will aid in locking the fins (7) in the deployed position. As the fins (7) translate fully through the channel and rotate back in line with the hubs (6), the screws (8) lock the fins into the end of the "s" channel locating the fins (7) in their deployed state. This can be seen in figure 3.

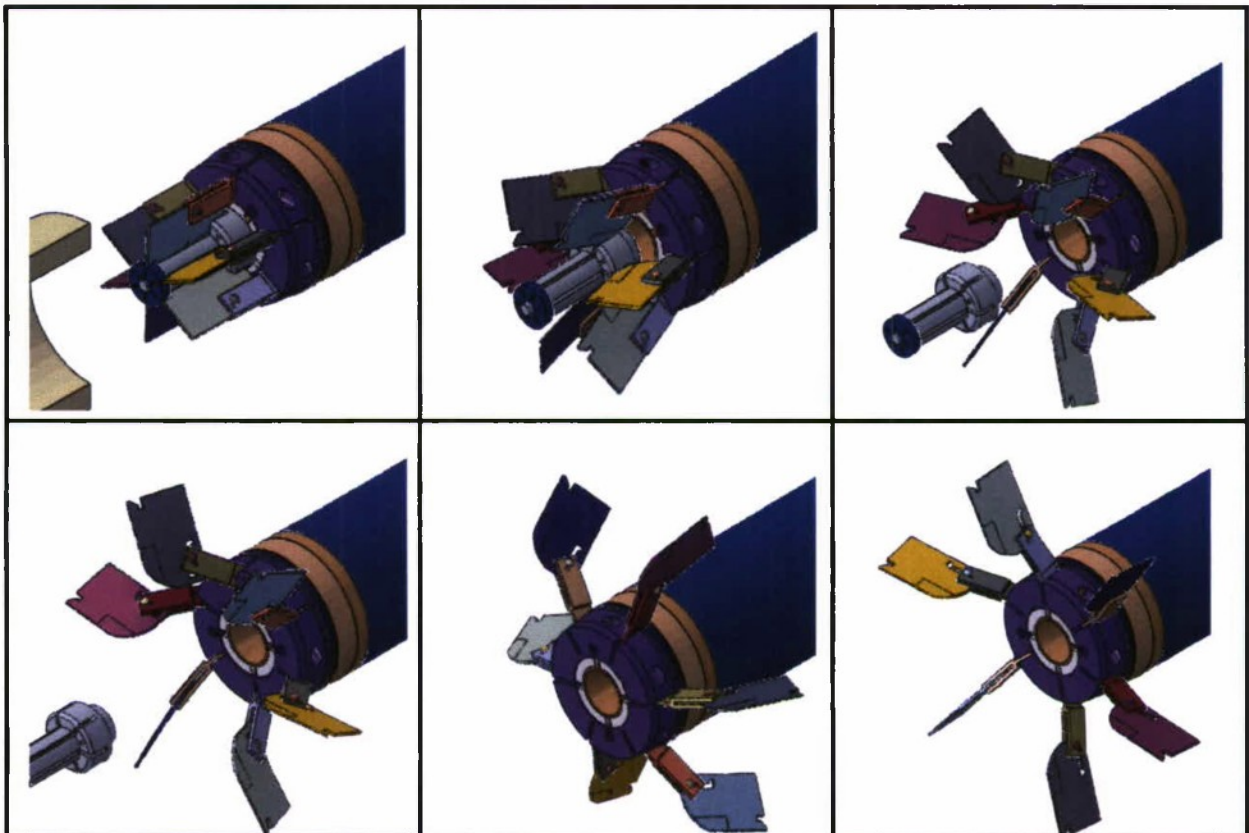


Figure 5
Side view and cross-section view of the extending fin sub-assembly in both the stowed and deployed configuration detailing the spring locking lever

PROOF OF CONCEPT

The extending fin base was modeled so that proper analysis could determine the feasibility of the design. Using Abaqus, finite element analysis software, the analyst was able to simulate the extending fin base design with the loads and boundary conditions found in the gun launch environment. Based on the results of the analysis, one can see that from a kinematic and physical perspective, there is effective fin deployment. This deployment process is clearly seen in figure 5. An area of concern is in the structural integrity of some components, but through further structural analysis, material down-select, and design iterations - those issues can be resolved.

EXTENDING FIN APPLICATION

The deployable extending fin base kit is being examined and considered as a tactical solution with the M913 or M1. Figure 6 displays the configuration of the assembly, which includes a M913 warhead with the extending fin base/rocket motor section fastened to the rear of the warhead as its stabilizing device. Additionally, a precision guidance kit (PGK) would fasten into the fuze well and act as the guidance mechanism.

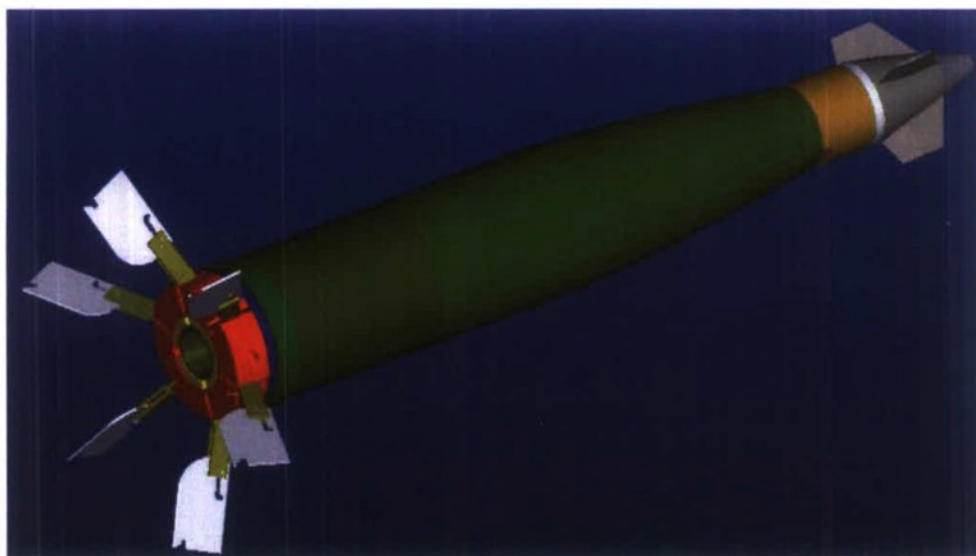


Figure 6
Isometric view of a M913 with a PGK and the extending fin base kit

AEROBALLISTIC ANALYSIS

The aeroballistic analysis of the proposed application resulted in a significant increase in the projectile's stability margin without sacrificing cartridge intrusion. The extension pushes the fin blade outward by approximately 0.7 in. The static margin or difference between center of pressure and center of gravity (CG) was increased by 80%. To compare with computational fluid dynamics (CFD) results, a representative fin design was modeled with Missile Datcom release 7. Missile Datcom is an aero-prediction software tool developed by engineers at Wright-Patterson Air Force Base, Ohio. The fin model was modified to match the stability margin as provided by the CFD results. This updated model was then applied to the M913 projectile with the PGK fuze unit.

The overall projectile length from fuze tip to base is 25.994 in. As part of the base design, the baseline very affordable precision projectile rocket motor was integrated into the M913 design. This rocket section was designed with two material properties (steel and titanium). Both base materials were analyzed as part of this study. Figure 7 shows a cut away view of the modified M913 configuration.

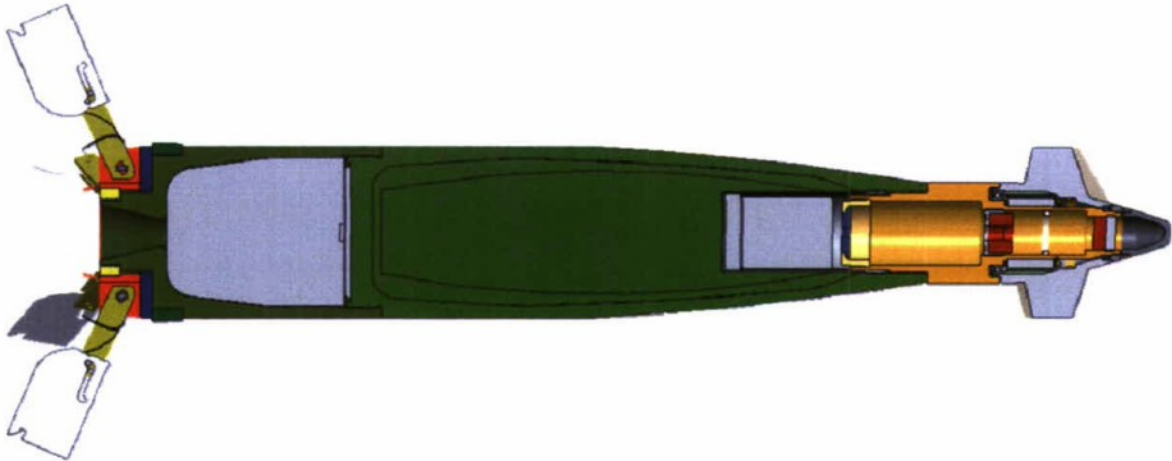


Figure 7
Cross-section view of a M913 with a PGK and the extending fin base kit

Six Degree-of-Freedom Aerodynamic Coefficients

The full sets of six degree-of-freedom (6DOF) coefficients were generated for both base designs with Missile Datcom. As a result of the different base material, there are differences with the aero coefficients. These differences are a result of applying the appropriate CG location for each base configuration. In general, the steel base has a CG that is further back relative to the nose tip by approximately 0.5 in. or 0.13 calibers. The effect of this difference makes the steel base slightly less stable at muzzle exit, but more maneuverable when guiding.

Three Degree-of-Freedom Trajectory Simulation

To evaluate the ballistics performance of the modified M913 configuration, the 6DOF coefficients were reduced to a subset needed for running a three degree-of-freedom (3DOF) simulation. The simulation modeled ballistics, rocket motor, and glide-out trajectories. The muzzle velocity assumed for all trajectories and both base designs were 500 m/s. This velocity was chosen because comparable projectiles of the same mass were gun fired and achieved similar velocity magnitudes. For the ballistic trajectory, the quadrant elevation (QE) was optimized for maximum range. The QE was set to 45 deg or 800 mils. Results for the steel and titanium bases indicated a maximum range of 10,585 and 10,202 m, respectively. The nominal trajectory with rocket motor and the gliding stage increase the maximum range to 19,203 and 17,924 m for the steel and titanium base, respectively. These trajectory results are displayed in figures 8 and 9.

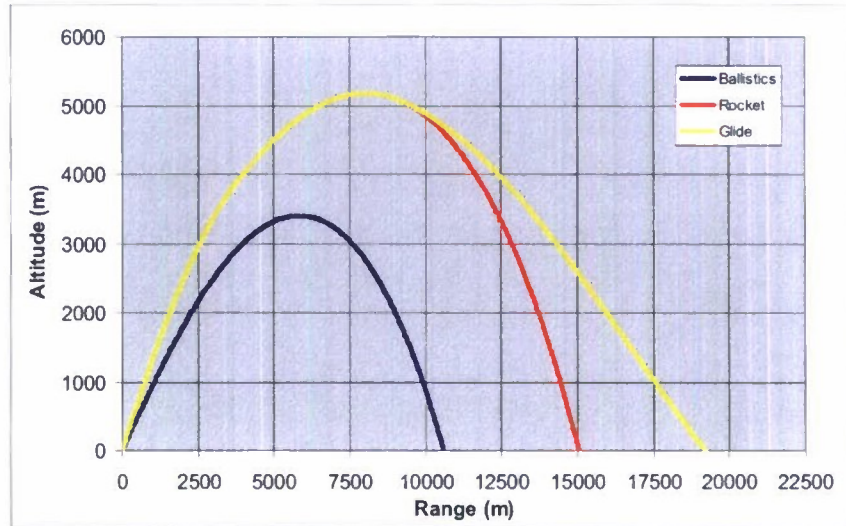


Figure 8
Nominal trajectories for steel base

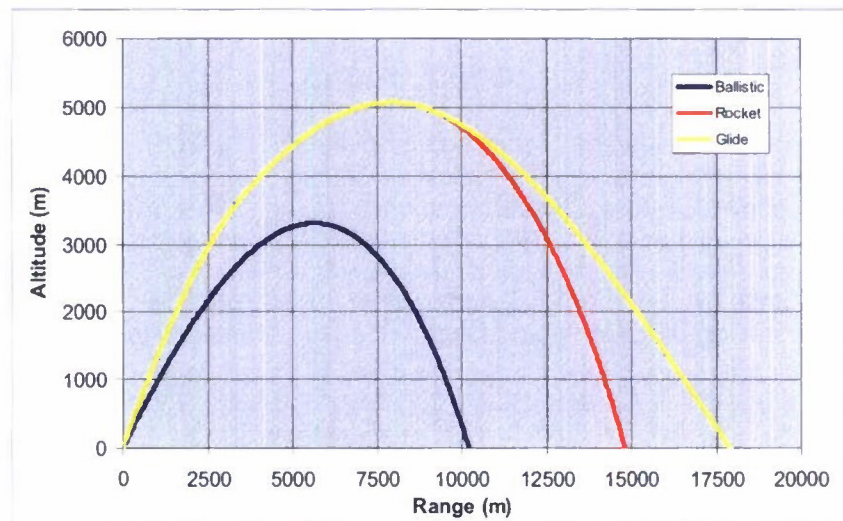


Figure 9
Nominal trajectories for titanium base

The final set of trajectories simulated was to generate a comparison of the maximum maneuver authority. For this case, the lift vector is rotated 360 deg. The reference point for this basket is the non-maneuver rocket trajectory impact point. Figure 10 displays these results.

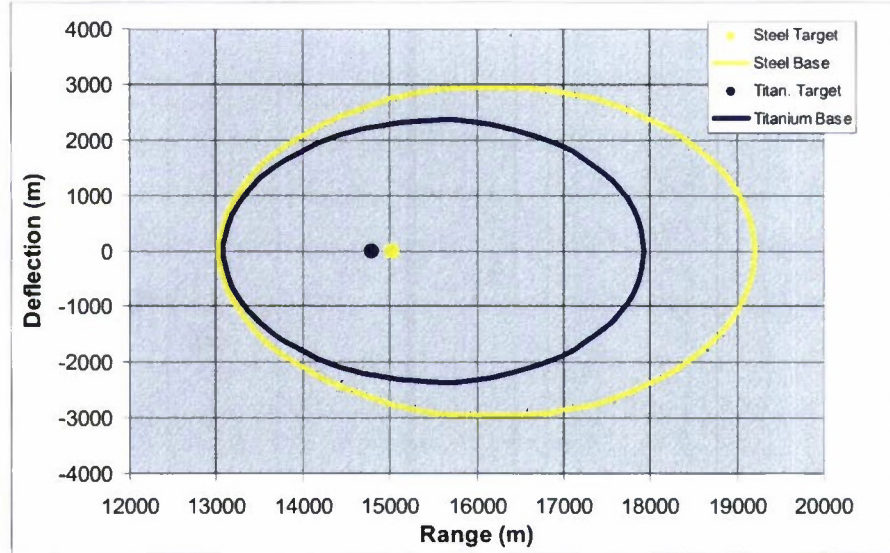


Figure 10
Maneuver basket for both base designs

CONCLUSIONS

The extending fin design has promising potential as a base kit concept for a 105-mm caliber projectile. With the unique and practical extending fins, aeroballistic stability can be achieved for the shorter 105-mm projectiles. In concept, they have proven to deploy upon muzzle exit as per the design intent. The extending fins also provide the 105-mm caliber projectiles with stability while still maintaining maneuver authority for guidance. Through more design iterations, finite element analysis, and testing - the concept can mature and become a feasible option for adding precision guided technology to 105-mm caliber artillery.

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